Regional Environmental Change (2020) 20:138
https://doi.org/10.1007/s10113-020-01723-5

ORIGINAL ARTICLE

Towards environmentally sound intensification pathways for dairy development in the Tanga region of Tanzania

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Received: 24 March 2020 / Accepted: 30 October 2020

Abstract

The gap between milk demand and domestic supply in Tanzania is large and projected to widen. Meeting such demand through local production of affordable milk presents an opportunity to improve the welfare of producers and market agents through the income and employment generated along the value chain (VC). Efforts to maximize milk yields, production and profitability need to be balanced with long-term sustainability. We combined environmental and economic ex-ante impact assessments of four intervention scenarios for two production systems in the Tanzanian dairy VC using the CLEANED model and an economic feasibility analysis. Intervention scenarios propose increases in milk production through (i) animal genetic improvement, (ii) improved feed, (iii) improved animal health and (iv) a package combining all interventions. Results show that economically feasible farm-level productivity increases of up to 140% go hand-in-hand with increased resource-use efficiency and up to 50% reduction in greenhouse gas (GHG) emission intensities. Absolute increases in water, land and nitrogen requirements in mixed crop-livestock systems call for careful management of stocks and quality of these resources. An overall rise in GHG emissions is expected, with a maximum of 53% increase associated with an 89% increase in milk supply at VC level. The CLEANED tool proved effective to evaluate livestock interventions that improve incomes and food security with minimal environmental footprint. Here, our simulations suggest that due to current low productivity, the greatest efficiency gains in combination with relatively low increases in total GHG emissions can be made in the extensive agro-pastoral dairy systems, which represent the majority of herds.

Keywords Livestock development · Dairy · Ex-ante impact assessment · Environmental sustainability · Cost-benefit analysis · Decision-making

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Communicated by Luis Lassaletta

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Introduction

East Africa (EA) is endowed with immense livestock resources representing the largest proportion of Africa's livestock population (FAOSTAT 2015). The livestock sector is a source of livelihoods, and provides food, income and employment for many millions of people in the region. This is particularly the case in Kenya, Tanzania and Uganda, which are home to a vibrant smallholder dairy sector. In many East-African countries, livestock production is an important contributor to the gross domestic products (GDP) and foreign currency export earnings (AU-IBAR 2015). Although the livestock sector is expanding in EA, the rate of growth does not match the increased demand for livestock products being experienced in the region and beyond. Low livestock productivity is one of the principal reasons for the inability of domestic production to meet the demand for livestock products.

In Tanzania, agriculture employs about 75% of the total labour force and contributes one-third of the country's agricultural GDP (URT 2013), and in turn about one-third of this is from the dairy sector (URT 2011). The annual domestic milk production of 1.8 million litres (FAOSTAT 2015) is estimated to meet only about "two-thirds" of the milk demand and this supply gap is projected to continue to widen in the near to medium future (Kurwijila et al. 2012; Michael et al. 2018). The income and employment that could be generated by affordable local dairy production, processing and marketing to meet this unmet milk demand presents an important opportunity for improving the welfare of producers and their market agents (Omore et al. 2019). Unlike most agricultural enterprises, benefits propagated throughout the dairy VC are generated daily rather than seasonally. Dairy production is, therefore, considered to be one of the most promising agricultural pathways out of poverty and for inclusive development, especially in instances where women retain control over milk income (URT 2015). This is in line with African Union's Livestock Development Strategy, which envisions a transformation of the sector from the prevailing subsistence livestock production systems into vibrant market-oriented systems with an enhanced contribution to socio-economic development and equitable growth (AU-IBAR 2015).

Despite the opportunities and benefits that increased livestock production could bring to the Eastern African Region, it is widely observed that livestock systems are key drivers of global environmental degradation (Foley et al. 2011), including increased nutrient loads, GHG emissions, water use, grassland degradation and land-use conversion (Steinfeld 2006; de Vries and de Boer 2010; Godfray et al. 2018). Thus, the predicted demand increase for dairy products poses a danger that the necessary rise in livestock production could become environmentally unsustainable, particularly as many ecosystems in the EA region are already under heavy pressure.

Efforts to maximize milk yields, production and profitability thus need to be balanced with long-term sustainability and environmental stewardship. It is therefore important to assess potential environmental impacts before embarking on large-scale development projects geared towards livestock production intensification and VC transformation (Notenbaert et al. 2016a). We developed an indicator framework for ex-ante assessments of environmental impacts of development interventions in livestock VCs, i.e. the Comprehensive Livestock Environmental Assessment for improved Nutrition, a secured Environment and sustainable Development (CLEANED). It estimates biomass, water and nutrient flows and assesses three dimensions of environmental impacts across different spatial and temporal scales: (1) water use, (2) soil health and (3) greenhouse gas emissions. The CLEANED framework is intended to support decision-making and to help prioritise the development action of governments, donors, NGOs and farmer organisations in data-scarce environments (Notenbaert et al. 2014).

In this paper, we take a consultative approach, soliciting input from local stakeholders and experts, to assessing the impacts of four production-enhancing intervention scenarios for two dairy production systems in the Tanga Region, Tanzania: (i) introduction of improved dairy breeds, (ii) improved feed availability, especially during the dry season, (iii) improved animal health, (iv) all three technology interventions combined together. We describe and compare the scenario outputs in three ways: (a) their impact on productivity and total milk supply to the market, (b) their economic feasibility, (c) their environmental impacts in terms of land requirements, water use, GHG emissions, soil erosion rates and soil nutrient balances. Finally, we discuss the opportunity of simultaneous appraisal of different impact dimensions to support evidence-based discussions on environmentally sound intensification pathways for the Tanzanian dairy VC.

Materials and methods

The CLEANED approach

Our study follows the concepts and guidelines of the CLEANED framework as described in Notenbaert et al. (2014). It is an indicator framework for ex-ante environmental impact assessment. It has been operationalised in an excel model, CLEANED-X, which focuses on three environmental dimensions: water use, soil health and GHG emissions. In addition to the assessment of environmental impacts, a simple enterprise-level cost-benefit analysis (CBA) is carried out to assess if the proposed intervention scenarios make economic sense for livestock keepers.

CLEANED does not assess the impacts associated with the full farm but is limited to the livestock enterprise only. It estimates the impacts associated with crop production—such as land requirements, nitrogen (N) balance and nitrous oxide (N_2O) emissions from soils—from the feed production areas only and does not include impacts associated with other crops potentially cultivated on the farm. On the farm input supply, the only environmental externalities included are those associated with fertilisers used for feed production. Although potential changes in transport, both from input and to output markets, might be associated with important changes in environmental costs, they are excluded from the analysis. The assessment is therefore not a full VC assessment in its true sense. Apart from considering losses along the VC, the model only takes pre-farm gate activities into account.

The CLEANED framework prescribes a stepwise procedure for carrying out an ex-ante impact assessment. In a first step, the study area is defined, and different types of livestock enterprises characterised. For each of the livestock enterprise types, baseline assessments are run and the potential impacts of different intervention scenarios estimated so that the potential impacts can be compared against the baselines. In a last step, an overall VC-level impact is calculated (Fig. 1). The following sections summarize how each of these steps and sub-steps was operationalised in the dairy VC in the Tanga region of Tanzania. More detailed information about the actual calculations can be found in the supplemental information.

Study area

The study focuses on the Tanga region of Tanzania. The area is home to the largest milk processing plant in the country (Tanga Fresh Ltd) which handles about 60,000 l daily (Cadilhon et al. 2016). Several development projects have been involved in supporting dairy production in the Tanga region. The Government of Tanzania and several national and international development partners are spearheading operation "Maziwa Zaidi" ("more milk" - https://maziwazaidi.org/) to increase milk production in the country, including in the Tanga Region (Cadilhon et al. 2016). The region is located in the coastal humid to semiarid climatic zone (FAO 2012), characterised by erratic rainfall patterns and large spatial and temporal variation in accessible surface water for agricultural or domestic use. In general, both crop and livestock production are fully reliant on rainfall in this area.

The dairy sector in the Tanga region shares characteristics with the main dairy production systems identified in Tanzania (Kurwijila et al. 2012). In our study, the characteristics, scale and spatial extent of the Tanga dairy production systems were captured using participatory mapping exercises during a multi-stakeholder workshop organised in Lushoto in June 2014 (Morris et al. 2014). In this data-gathering approach, issues being assessed are discussed and mapped by the local stakeholders, so that the knowledge produced is rooted in the local community and is spatially explicit (Cinderby et al. 2011). This information was validated and further refined by triangulation with existing spatial and household data (Mangesho et al. 2013; Omondi et al. 2018; Silvestri et al. 2014), field visits and expert knowledge.

The participants of the workshop in Lushoto identified four broad categories of livestock production enterprises: (i) ranching, (ii) intensive zero-grazing, (iii) semi-intensive and (iv) extensive agro-pastoral. The ranching system is rare, with only two known ranches in the region, with both entirely focusing on beef production. This system was excluded from further analysis. The differences in management and feeding practices between the intensive zero-grazing and semi-intensive systems were too small to produce significantly different environmental impacts. Thus, for further analysis, these two systems were combined and labelled "mixed crop-

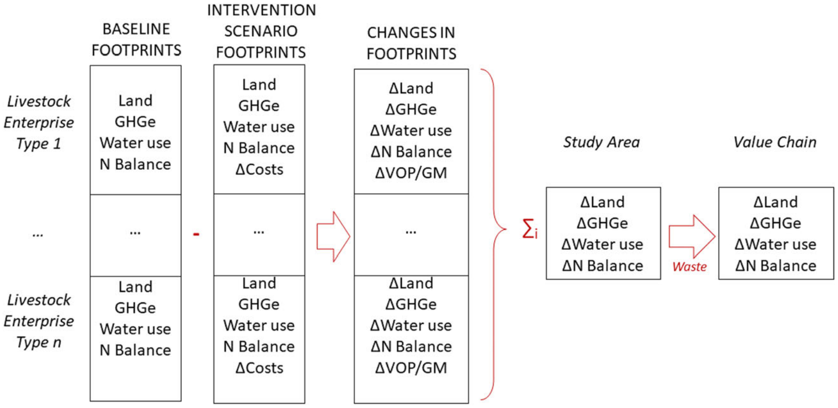

Fig. 1 Conceptual figure showing the workflow of CLEANED ex-ante impact assessments. The enterprise-level changes in environmental footprints are summed up to estimate the changes in environmental footprints at study area level. Impact indicators include land requirements for feed production, greenhouse gas emissions (GHGe) associated with feed and milk production, water used for feed production and nitrogen balances in the feed producing areas. At value chain level, the loss of milk is taken into account to express these impact indicators per unit of milk consumed instead of per unit of milk produced

livestock systems". The detailed description and characteristics of the two systems included for analysis, (i) extensive agro-pastoral systems and (ii) mixed crop-livestock systems, can be found in the Supplemental Information (SI).

Livestock intervention scenarios

As part of the "Maziwa Zaidi" program in Tanzania, sixteen village-level innovation platforms (IPs) were established in Tanga. These IPs are designed to bring together different agents in the VC, including farmers, traders, food processors, researchers and government officials, to provide a useful space for local stakeholders to jointly identify constraints, opportunities and devise and implement solutions. Further information about the innovation platforms can be found in the Supplemental Information. Their advantage over conventional methods, e.g. surveys and VC analyses, is that they can rapidly identify key constraints and opportunities by drawing on extensive local knowledge. Furthermore, local people are more likely to take ownership of the solutions they have actively identified, increasing their likelihood of success (Homann-Kee Tui et al. 2013). In May 2014, these IPs developed "site-specific plans" focusing on relevant interventions for dairy VC intensification (Twine et al. 2017). We carefully examined the 16 site-specific plans and extracted four distinct scenarios of production-enhancing technological interventions. For the purpose of this study, each of these intervention scenarios was described in terms of changes in relevant system characteristics, according to literature review and expert opinion. The four scenarios (A–D) are briefly described below. We refer to table 2 in the SI for a more detailed description of changes in input and parameter values.

(A) "Animal genetic improvement": This scenario represents the historically most preferred strategy for driving productivity improvements within the region, whereby more exotic animal genotypes are introduced, often through cross-breeding (Wilson 2018; Marshall et al. 2019). Within the mixed crop-livestock system, this results in increased live weight of cattle but restricted milk yield increases due to the limiting effects of diseases, such as mastitis and other infections. Within the extensive agro-pastoral system, the changes towards more exotic genetics are expected to go hand-in-hand with a reduction of herd size to compensate for restricted sturdiness of the animals and reduced reproductive function, but at the same time with an important increase in milk yield per animal due to significantly increased genetic potential. No changes in feedmix are assumed in this scenario, only increased feed quantity.

(B) "Improved feed": This scenario increases nutrient provision to the cattle herds within the two systems. Livestock feed baskets are altered to demonstrate the inclusion of legumes and improved forage preservation for use during the dry season when energy deficit limits milk yield. Within both systems, increases in milk yield and live weight are expected to correspond to an increase in metabolisable energy availability for the well-nourished and thus stronger animals. These increases are, however, quite limited as they are assumed to be hampered by health status in the mixed crop-livestock and by genetic constraints in the extensive agro-pastoral system. In addition, the herd sizes are assumed to increase.

(C) "Improved animal health": This scenario represents an increase in veterinary interventions, both prophylactic and dynamic care, promoting reduction in production limiting diseases. In this scenario, the intensive mixed crop-livestock system exhibits increased live weight, increased milk yield and increased herd size, following improved calf survival rates; limits are still imposed by nutritional restriction and breed characteristics. Within the extensive agro-pastoral system, the scenario implies increased milk yield and live weight and a more significant increase in herd size resulting from the greater impact of reduced calf mortality and greater reproductive health.

(D) "Combined interventions": The last scenario combines all three separate interventions into a situation where animals with higher genetic potential are subject to better animal health care and improved seasonal feed availability. This is assumed to result in increased animal live weight and higher milk yield because limitations imposed by health status, lack of feed or genetic potential are reduced. In the mixed systems, a significant increase in herd size is expected due to reduced calf mortality and adequate feed availability. Also in the agro-pastoral systems, the herd sizes are assumed to be quite large, though less than the current local herds, due to limiting reproductive function of the improved breeds.

Indicator calculations at enterprise level

We set up simple minimum-data calculations to estimate the following environmental footprint indicators (Mukiri et al. 2019; SI).

1) Productivity (kg Fat and Protein Corrected Milk (FPCM), kg FPCM/ha)
2) Land requirement (ha, ha/kg FPCM)
3) Soil loss (kg, kg/ha, kg/kg FPCM)
4) Soil nitrogen (N) balance (kg N, kg N/ha, kg N/kg FPCM)
5) Water use (m^3, m^3/ha, m^3/kg FPCM)
6) GHG emissions (kg CO_2-equivalent (CO_2-eq.), kg CO_2-eq./ha, kg CO_2-eq./kg FPCM)

The environmental indicators are all expressed as absolute values as well as intensities, on a per area as well as per product basis, i.e. per kg Fat and Protein Corrected Milk (FPCM) consumed. Comparisons with the baselines were expressed in percentage change.

In addition, we adopted a simple economic feasibility analysis that comprises the comparison of annual values of production (VOP) and the calculation of the change in gross profit (GP) based on the estimated costs of scenario implementation (see SI for more details).

Out-scaling of enterprise-level impacts to the VC level

The assumption underlying the out-scaling is that agricultural strategies are likely to have the same relevance for all enterprises of the same type and that the estimated enterprise-level impacts can be widely applied across the study area. Regional impacts were calculated based on an estimated attainable level of adoption of the respective scenario's technologies and the importance of each of the enterprise types in the area. For the Tanga region, we assumed that the total number of enterprises remained unchanged, and that 20% of them would adopt the intervention scenario. This percentage lies within the range of observed adoption of technologies in the East-African Dairy Development program (Kiptot et al. 2015). We assumed that the potential increase in milk supply would be fully absorbed by the market which is a realistic assumption given the high local demand. In order to calculate overall VC-level impact figures, the environmental footprint indicators of the individual livestock enterprises were multiplied by one-fifth (20%) of the estimated number of such enterprises and weighted averages calculated for the intensity indicators.

Results

Baseline situation

The dairy enterprises in Tanga are estimated to provide about 135,000 tons FPCM to consumers in the region (Table 1). The feed for the herds producing this amount of milk is grown on marginally less than 600,000 ha. About 24% of the land used for feed production is associated with rainfed mixed crop-livestock farms, which are producing 27% of the local milk consumed at a productivity of 525 FPCM/ha. About 73% of the milk is produced in the more extensive agro-pastoral systems (195 FPCM/ha), bringing down the average productivity in Tanga district to 235 FPCM/ha.

Due to large off-farm grazing areas, the total amount of soil lost in an agro-pastoral farm is about 20-fold the amount lost from a mixed crop-livestock farm (Table 2). When expressed in soil loss per area, on the other hand, the agro-pastoral systems lose less than the mixed crop-livestock systems. This is not surprising, as the agro-pastoral livestock production is typically taking place on flatter land with less rainfall. This, together with the continuous grasscover, compensates for the more erodible Fluvisol soils found here as compared to the annually tilled Andosols in the mountainous area of the mixed crop-livestock farms. Due to a higher stocking rate and animal productivity in the mixed crop-livestock systems, the amount of soil lost per kg FPCM is less than half of the loss per kg FPCM in agro-pastoral farms.

The soil N balance for livestock production in the mixed crop-livestock farms is negative, mostly because of the removal of feed biomass with only limited input of fertilisers, indicating that nutrients are mined at an average of about 58.5 kg N per hectare per year. Through manure collection from the stable and subsequent application to non-feed crops, about 51 kg N per ha is exported from the livestock to the crop enterprise. The agro-pastoral system exhibits a less negative N balance. Nitrogen losses, through grass and crop residue removal, leaching, gaseous losses and erosion, are partly compensated through recycling of feed-N back to soil through the urine and manure production of the relatively big herd. About 35% of this manure is assumed to be deposited during grazing in the off-farm grazing areas and none of the manure is assumed to be re-directed to the crop enterprise. As the milk productivity in the agro-pastoral enterprises is lower than in the mixed crop-livestock enterprises, the N losses per kg FPCM are estimated to be almost 65% greater.

The estimated water use per kg FPCM ranges from 1100 l in the mixed crop-livestock systems to about 2600 l in the agro-pastoral enterprises (Table 3), which is in line with the estimates by Sultana et al. (2014).

The dairy production from the ~9000 extensive agro-pastoral and 31,000 mixed crop-livestock enterprises (see SI) in the Tanga region is estimated to produce GHG emissions totalling to more than 400 thousand ton CO_2-eq. The agro-pastoral "farms" exhibit a higher GHG emission intensity (GHGe/unit of produce) than the mixed crop-livestock farms, mostly because of the lower quality of the animals' diet, the low milk yields and the substantial influence this has on methane ($CH_{4)}$-efficiency of enteric fermentation. Higher stocking rates of bigger and more productive animals result in an estimated doubling of GHG emissions per hectare in the mixed crop-livestock systems.

Environmental assessment of livestock management scenarios

Based on the assumed changes in per animal production and herd sizes and composition, the total milk supply is projected to increase under all scenarios. The largest relative supply gains would be made in the mixed crop-livestock farms and mostly so if the genetic, feed and animal health interventions were combined. The milk production increase in those farms

Table 1 Productivity and land requirement for feed production in the typical mixed crop-livestock and agro-pastoral enterprises and the Tanga dairy value chain. The absolute values under baseline conditions are shown, while the results of the scenarios are shown as changes to these baseline conditions

		Productivity		Land requirements	
		Total supply (kg FPCM)	Productivity (kg FPCM/ha)	Land used (ha)	Land used per product (ha/MT FPCM)
Mixed crop-livestock enterprise	Baseline	1157	525	2.2	1.9
	Genetics		–	–	–
	Feed	+++	+	–––	+
	Health	+++	+	–––	+
	Combined	+++	++	–––	++
Agro-pastoral enterprise	Baseline	10,862	195	55.7	5.1
	Genetics	++	+++	++	++
	Feed	++	+++	++	+++
	Health	++	+++	++	+++
	Combined	+++	+++	–	++
Tanga VC	Baseline	135,372,101	235	576,462	4.3
	Genetics		+		+
	Feed	++	++		++
	Health	+++	+++		++
	Combined	+++	+++	–––	++

–––: negative change of more than 50%, ––: negative change of 20–50%, –: negative change of 5–20%, +: positive change of 5–20%, ++: positive change of 20–50%, +++: positive change of more than 50%

is projected to go hand-in-hand with big increases in land requirements for feed production and associated increases in absolute soil loss. Under unchanged fertility management systems, these would be accompanied by an increasing negative N balance.

The land productivity (kg FPCM/ha) is expected to increase across livestock production enterprise types and scenarios. The only exception is the genetics scenario in the mixed crop-livestock enterprises. Under all scenarios, the live weight of the animals is assumed to increase and more beef would also be produced. Similarly, all envisioned intervention scenarios, apart from the genetic improvement, would have a positive impact on soil loss and N efficiency in the mixed crop-livestock systems, i.e. result in lower losses per kg FPCM and to a lesser extent per hectare. In the agro-pastoral systems, the impact on amounts of soil lost and N balances would be mixed. Impacts on soil erosion are mostly positive, apart from the absolute value under the “combined interventions” scenario. The same scenario is also projected to negatively affect absolute N loss and N loss per hectare, while efficiency in terms of N loss per unit milk produced improves across the scenarios.

In the mixed crop-livestock systems, the absolute total water use is expected to increase under all intensification scenarios due to larger feed requirements. In the agro-pastoral systems, only the combined intervention would be accompanied by a slight increase in water use. The water appropriated per unit of milk would however decrease across scenarios and production enterprise types. The only exception is the improved genetics scenario in mixed farms, as the land productivity is estimated to decline in that scenario.

All intervention scenarios, apart from the improved genetics, assume larger herd sizes with bigger and more productive animals. These herds are estimated to cause higher GHG emissions. In contrast to the generally higher total GHG emissions, we often see lower emission intensities, especially when expressed per unit product.

Economic feasibility

Applying an observed farm gate price of 0.38 and 0.30 USD per kg milk (see SI) in the mixed system and agro-pastoral systems, respectively, the baseline value of the total milk production in the Tanga region is about 42 million USD per year. This is expected to increase by between 6.7 and 105% under the genetics and combined intervention scenarios, respectively (Table 4). Considerable extra benefits can be expected from increasing live weight gain and manure production associated with the dairy intensification scenarios. Under the “combined interventions” scenario, for example, and applying a price of 0.060 USD and 0.0025 USD per kg manure, i.e. the prices farmers receive in the mixed crop-livestock and agro-pastoral areas respectively (see SI), the extra manure produced is estimated to be worth about 7 million USD.

The costs associated with the implementation of the intervention scenarios are listed in the SI. In addition to these costs,

Table 2 Productivity, soil loss and N balance in the typical mixed crop-livestock and agro-pastoral enterprises and the Tanga dairy value chain. The absolute values under baseline conditions are shown, while the results of the scenarios are shown as changes to these baseline conditions

		Productivity		Erosion				Nutrients	
		Total supply (kg FPCM)	Productivity (kg FPCM/ha)	Soil lost (kg)	Soil lost per area (kg/ha)	Soil lost per product (kg/MT FPCM)	N lost (kg N)	N lost per area (kg N/ha)	N lost per product (kg N/kg FPCM)
Mixed crop-livestock enterprise	Baseline	1157	525	4.2	1.9	3.7	− 129	− 58.5	− 0.11
	Genetics		−	−		−	−		−
	Feed	+++	+	−−−	+	++	−−−	+	++
	Health	+++	+	−−−		+	−−−	+	+
	Combined	+++	++	−−−	+	++	−−−	+	++
Agro-pastoral enterprise	Baseline	10,862	195	83.4	1.5	7.7	− 1952	− 35.1	− 0.27
	Genetics	++	+++	++		++	++		++
	Feed	++	+++	++	+	+++	++		+++
	Health	++	+++	++	+	+++	++		+++
	Combined	+++	+++	−	+	+++	-	−	++
Tanga VC	Baseline	135,372,101	235	893,088	1.5	6.6	− 21,836,692	− 37.9	− 0.24
	Genetics		+			+			+
	Feed	++	++	+		++			++
	Health	+++	+++			++			++
	Combined	+++	+++	−		++	−		++

−−−: negative change of more than 50%, −−: negative change of 20–50%, −: negative change of 5–20%, +: positive change of 5–20%, ++: positive change of 20–50%, +++: positive change of more than 50%

Table 3 Productivity, water appropriated for feed production and greenhouse gas emissions in the typical mixed crop-livestock and agro-pastoral enterprises and the Tanga dairy value chain. The absolute values under baseline conditions are shown, while the results of the scenarios are shown as changes to these baseline conditions

		Productivity		Water use			GHG emissions		
		Total supply (kg FPCM)	Productivity (kg FPCM/ha)	Total water use (m^3)	Water use per area (m3/ha)	Water use per product (m3/MT FPCM)	Total emissions (kg CO_2-eq.)	Emissions per area (kg CO_2-eq./ha)	Emissions per product (kg CO_2-eq./MT FPCM)
Mixed crop-livestock enterprise	Baseline	1157	525	1234	560	1.1	2647	1202	3.7
	Genetics		−	−		−	−		−
	Feed	+++	+	−−−		+	−−−	−	++
	Health	+++	+	−−−		+	−−−		+
	Combined	+++	++	−−−		++	−−−	−	++
Agro-pastoral enterprise	Baseline	10,862	195	28,570	513	2.6	36,271	652	7.7
	Genetics	++	+++	++		++	+	−	++
	Feed	++	+++	++	−	+++	−−	−−−	+++
	Health	++	+++	++	−	+++	−−	−−−	+++
	Combined	+++	+++	−		++	−−	-	+++
Tanga VC	Baseline	135,372,101	235	299,119,461	519	2.2	413,748,868	718	6.6
	Genetics		+			+			+
	Feed	++	++			++	−	−−	++
	Health	+++	+++			++	−−	−−	++
	Combined	+++	+++	−		++	−−	−−	++

−−−: negative change of more than 50%, −−: negative change of 20–50%, −: negative change of 5–20%, +: positive change of 5–20%, ++: positive change of 20–50%, +++: positive change of more than 50%

an opportunity cost of 52 and 25 USD per ha per year was applied to the changes in land requirements for feed production in the mixed crop-livestock and agro-pastoral enterprises, respectively. The resulting changes in GP after 5 years were positive for each of the intervention scenarios (Fig. 2). The value of the extra milk and manure production outweighed the investments, maintenance costs and opportunity costs associated with implementing the interventions. From the perspective of a mixed crop-livestock enterprise owner, it appears to make economic sense to invest in a package of combined genetics, feeds and animal health interventions. In contrast, for an agro-pastoralist, the highest returns may be expected from a feed or an animal health intervention. Due to the low primary productivity of the grazing lands upon which these systems depend, the increased milk production in the combined scenario, with its large amounts of feed required for energy and protein provision, results in large increase in land requirement. The projected increase in milk production does not outweigh the associated increase in land requirement.

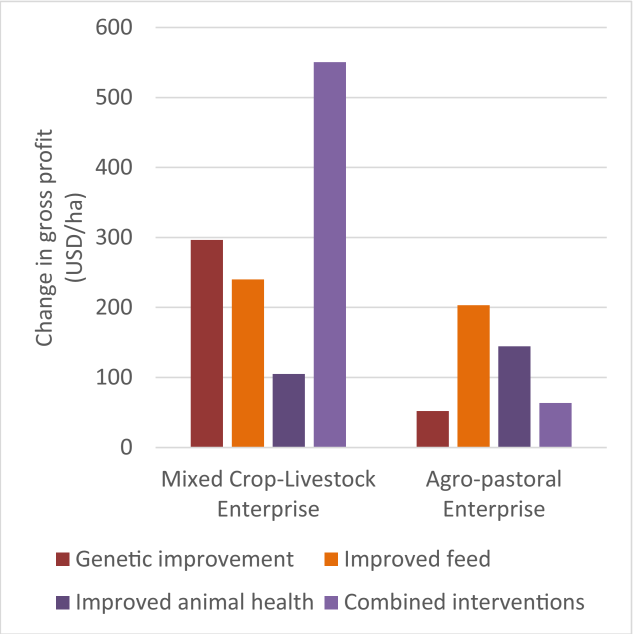

Fig. 2 The calculated changes in gross profit at the enterprise level accumulated until the 5th year

Discussion

The study shows that there are large environmental footprints associated with the different types of dairy production systems in the Tanga region of Tanzania, which is in line with global assessments (de Boer 2003; Capper et al. 2009; Gerber et al. 2010; Guerci et al. 2013; Sultana et al. 2014). Yet, from the baseline situation of both pastoral and mixed crop-livestock systems, increases in productivity (up to 89%) may outweigh expected increases in GHG emissions (53%). These findings corroborate the claims (e.g. Boadi et al. 2004; Martin et al. 2010; Thornton and Herrero 2010; Cederberg et al. 2013; Gerber et al., 2013; Rojas-Downing et al. 2013; Herrero

Table 4 Productivity and the value of production in the typical mixed crop-livestock and agro-pastoral enterprises and the Tanga dairy value chain. The absolute values under baseline conditions are shown, while the results of the scenarios are shown as changes to these baseline conditions

		Productivity		Value of production			
		Total supply (FPCM)	Productivity (FPCM/ha)	VOP Milk (USD)	VOP Manure (USD)	Total Value of Production (USD)	Value of Production (USD/ha)
Mixed crop-livestock enterprise	Baseline	1157	525	475	165.1	640.1	290.7
	Genetics		−		+		−
	Feed	+++	+	+++	+++	+++	+
	Health	+++	+	+++	+++	+++	
	Combined	+++	++	+++	+++	+++	++
Agro-pastoral enterprise	Baseline	10,862	195	3000	160.3	3160.3	56.8
	Genetics	++	+++	++	−−	++	+++
	Feed	++	+++	++	++	++	+++
	Health	++	+++	++	++	++	+++
	Combined	+++	+++	+++		+++	+++
Tanga VC	Baseline	135,372,101	235	42,278,400	6,656,571	48,934,971	84.9
	Genetics		+	+		+	+
	Feed	++	++	++	+	++	+++
	Health	+++	+++	+++	+++	+++	+++
	Combined	+++	+++	+++	+++	+++	+++

−−−: negative change of more than 50%, −−: negative change of 20–50%, −: negative change of 5–20%, +: positive change of 5–20%, ++: positive change of 20–50%, +++: positive change of more than 50%

et al. 2016) that environmental footprints can be reduced and GHG emission intensity gains can be made through productivity-enhancing interventions. They provide evidence for supporting more environmentally sound intensification pathways for dairy development in the Tanga region and similar production systems in East Africa.

Big differences exist across dairy enterprises

The types of dairy enterprises studied in the Tanga region differed in productivity, natural resource use and environmental footprints. The productivity of agro-pastoral dairy production was low as compared to more intensive production in the mixed crop-livestock farms. The differences in productivity to a large extent reflect the intrinsic agricultural potential of the locations where the different types of production are taking place. Pastoralist dairy enterprises in the low and more arid areas cannot be expected to be as productive as the mixed systems in the highlands with their more favourable soil, water and climatic conditions. Taking these local conditions into account, we do not consider a transformation of the agro-pastoral systems into intensive mixed systems based on zero-grazing to be feasible. It also needs to be noted that agro-pastoral enterprises typically also supply considerable amounts of beef and live animals to the market. The total live weight gain of a typical agro-pastoral herd of 50 adult animals and 20 calves is estimated to be about 2500 kg per year compared to the production of about 10,000 kg milk per year. If a biomass-based allocation of environmental footprints between beef and milk were applied, it would reduce the reported milk footprint by about a quarter. Additionally, as people in the more marginal lands have often limited access to banks and other financial services, their animals are used to store and manage wealth and offer an important buffer in times of crisis (Siegmund-Schultze et al. 2011).

In addition to the multi-functionality of keeping livestock, which is especially important in the agro-pastoral systems, the milk production in these systems is taking place on land that is much less suitable for growing food crops. While the mixed dairy enterprises in the highlands might thus exhibit higher productivity, they also exhibit a higher opportunity costs for the land, as this land is highly suitable for food crop production (Van Zanten et al. 2016). A similar logic applies to the water appropriated per kg FPCM, where the mixed systems appear to perform much better than the agro-pastoral systems. Biomass growth on marginal lands, with sparse vegetation and a large fraction of soil evaporation, the water use per unit feed cultivated or biomass grazed is often several magnitudes higher than on more suitable lands. This is one reason behind more water-efficient livestock production in mixed systems. Our model does not yet include such suitability perspective, as proposed by, e.g., Van Zanten et al. (2016) and Ran et al. (2017), which would make it possible to appraise alternative water use options. It is, however, important to keep this difference in opportunity cost and multi-functionality of livestock in mind when comparing dairy productivity. The sole focus of the current study on milk production is an important limitation, as the calculations of environmental footprints change depending on the functions included, an argument echoed by, for example, Weiler et al. (2014).

The negative N balances are in line with the findings from Kihara et al. (2014). They are likely to lead to nutrient mining and could have an impact on future yields (Bindraban et al. 2000). This can mostly be attributed to the removal of N through the feed crops and food crop residues which is not compensated for by N input, be it from chemical or organic origin, nor by N fixation by leguminous crops. The N losses per hectare are estimated to be larger for the mixed crop-livestock systems than the agro-pastoral systems. This is in line with the findings of Snijder et al. (2013) who argue that the transition from traditional herding of cattle in communal grasslands to sedentary husbandry systems based on home-grown forages has a negative effect on net nutrient balances. They recommend importing nutrients into the system in combination with a radical improvement of manure management technology. The negative soil N balance associated with the livestock enterprises in the mixed crop-livestock systems does provide a co-benefit to the farmers in the form of manure redirected to crop production on the same farm. On many farms, this is seen as an important function of livestock as the purchase of mineral fertilisers is, in general, low and expensive (FAOSTAT 2018) and frequency of manure application has been shown to be associated with higher yields (Kihara et al. 2014).

In terms of GHG emissions, the low productivity of the dairy production systems in Tanga is associated with GHG emission intensities well above the global average of 2.4–2.8 CO_2-eq. per kg of FPCM associated with milk production, processing and transport (Gerber et al. 2010; Opio et al. 2013). The relatively lower productivity in the agro-pastoral systems was associated with higher emission intensities per litre of milk than the ones in the more productive mixed crop-livestock system. The higher emissions are mainly explained by high levels of methane produced by enteric fermentation. This finding is in line with FAO's global assessments of sources of dairy-related GHG emissions (Gerber et al. 2010, 2013a, b).

Options for reducing environmental footprints exist

All modelled scenarios resulted in agro-pastoral enterprises emitting less GHGs per unit of product, with emission intensity reductions ranging from five to 40% (Table 3). Also in the mixed crop-livestock farms, improvements in emission intensity are expected. They are projected to be smaller than in the agro-pastoral farms. The only exception was the improved genetics scenario in the mixed farms, where the body weight of the animals is assumed to increase—and thus also energy requirements for maintenance—while their increased genetic potential in terms of milk production is not met because the feeding regimes are not adapted accordingly. The introduction of such intervention resulted in a projected 6.5% increase in emission intensity. Productivity-enhancing interventions would all result in large increases in absolute GHG emissions and GHG emissions per unit of area (Table 3). Other trade-offs between environmental impact categories include a growing demand for land and water for feed production in all productivity-enhancing interventions in the mixed farms. It is important to note that the expected expansion of land use for feed production could have several negative side effects. If feed crops replace food crop production, this might have trade-offs in terms of overall food security. If non-agricultural land would be converted, negative impact on biodiversity could be expected. A key limitation of this study is that we cannot identify where the extra feed cultivation will take place and what land use it will replace. This influences the location-specific erosion, nutrient and water change estimates and the implications of those changes.

Under current assumptions, the genetics scenario is of general concern in the crop-livestock systems. Through singular trait selection without the associated infrastructure of artificial insemination, quality nutritional provision, disease prevention and treatment, the perceived effects of improved genetics could conceivably present as negative. Genetic improvement in the mixed systems will benefit from the growing interest in the use of genomic approaches and for developing new breeds that have the adaptation and resilience of indigenous breeds combined with the productivity of exotic breeds (Marshall et al. 2019). In addition, they will need to be complemented with feed and animal health interventions and advice on appropriate animal husbandry, fertility and manure management.

In general, the environmental indicator assessment results in this study corroborate previous findings (e.g. Thornton and Herrero 2010) that intensification in the mixed crop-livestock systems mostly goes hand-in-hand with absolute increases in resource use. Gains were however possible in terms of efficiency, expressed as resource use or GHG emissions per unit of production. As Tanzania has included mitigation through livestock systems in their Nationally Determined Contributions (URT 2015), pursuing such reduced GHG emission intensity is a relevant climate strategy and also in line with the recommendations of the Livestock Master Plan (Michael et al. 2018).

The interventions also make economic sense for livestock keepers. Combined interventions were estimated to be more environmentally friendly than isolated technologies. This is in line with the findings of, e.g., Cortez-Arriola et al. (2014) and Mayberry et al. (2017) who found that packages of interventions rather than single interventions are required to bridge existing dairy yield gaps. Future work and inclusion of more scenario analyses allowing the elucidation of the marginal effects of each of the interventions could provide more detailed insights to this effect. In addition to the more sophisticated technology scenarios brought forward by the stakeholders, simple improved husbandry interventions such as the provision of water ad libitum, better-designed housing and udder hygiene will also affect the animal health status and productivity and could be included in the promoted intervention scenarios too. The fact that the intervention scenarios, and most notably the genetics improvement one, exhibit differential impacts in different systems clearly points to the importance of careful context-specific planning. This was also concluded by, e.g., Giller et al. (2011) and is one of the important recommendations in FAO's guidelines on climate smart agriculture (FAO 2013).

Towards evidence-based decision-making

This study set out to demonstrate that ex-ante environmental assessments can help unpack complexities across interventions and potential impacts to inform environmentally sound investments in the livestock sector. Choosing the most beneficial (least negative impacting) interventions is challenging because different objectives are often dynamically interconnected, and trade-offs might be experienced in the pursuit of multiple, sometimes competing, goals (Klapwijk et al. 2014; Salmon et al. 2018). Quantitative estimates of the impacts of potential interventions can inform the choice of interventions (e.g. Noltze et al. 2012). The current evidence base is, however, considered to be inadequate to support effective decision-making, and largely inaccessible to decision-makers at the national and local levels (Lipper et al. 2014). Policymakers, scientists and extension educators urgently need examples of how to identify technologies and visualize their relative performance across multiple domains (Snapp et al. 2018). This study demonstrates that rapid ex-ante assessments of alternative intervention scenarios can provide such information. Through applying the CLEANED assessments, we provided information about different impact dimensions simultaneously to inform discussions of development pathways in the Tanzanian dairy VC.

This assessment only looks at a limited number of indicators of sustainability, focusing on four environmental dimensions complemented with a simple calculation of economic feasibility at farm level. The social dimension of sustainability is not included in the assessment. In terms of environmental dimensions, changes in ecological resilience, water quality, pollution and biodiversity are also likely to occur. If interventions are, for example, narrowly focused on increasing productivity through increasing input and management requirements, there is considerable potential for losing much of a system's resilience (Salmon et al. 2018). Indigenous livestock breeds, for instance, are generally considered to be better adapted to challenging local environments (Berman 2011). It is important to note that the tool was conceptualised as a rapid user-friendly assessment tool with limited data requirements. This informed the limited number of environmental dimensions considered and the choice of simple mathematical equations for impact quantification, thereby losing some of the inherent complexity in agricultural systems and the critical feedback loop with changes in natural resource stocks. We thus recommend the use of the tool for a quick first-step evaluation of the potential impacts of a wide range of interventions, to identify sub-sets of promising specific interventions for evaluating using more detailed quantitative information, to estimate aggregated impacts in certain regions, or to link them to global and regional change models (Notenbaert et al. 2014). The complexity of agricultural systems also brings about the need to consider not only environmental but also social, human and economic aspects (Loos et al. 2014; Smith et al. 2017). The interventions are, for example, likely to have significant impacts on social relations, labour requirements and employment along the value chain, nutrition and market dynamics. For livestock keepers, one of the main incentives to move towards more intensified systems is to achieve higher income, especially where land or labour is scarce (Salmon et al. 2018). Our results suggest that all intervention scenarios would make economic sense for livestock keepers. The long-term economic benefit for livestock producers, however, relies heavily on the market demand and the opportunity to sell all additional produce now and in the future. Also, how the extra income is allocated within the households and how this could influence intra-household power relations and control over resources is equally not assessed. Another element missing in our study is the inclusion of local substitution effects, such as potential changes in land-use allocations and people's dietary choices, and the potential off-site impacts in terms of loss of markets and income in the countries or regions where milk is currently being imported from. This shows that the environmental assessments in themselves are useful and interesting, but that they are even more powerful when carried out alongside non-environmental assessments (Notenbaert et al. 2016a). Thus, we see the application of the approach illustrated in this paper not as a stand-alone activity but as complementary to other processes and assessments carried out in preparation for livestock sector development.

In terms of process, we have to take into account that behavioural uncertainties can affect the practical value of predictions from quantitative analysis (Swim 2009). To ensure that the results and insights of the assessments are taken up and contribute to more-informed planning, it is important to integrate them in decision-making processes through early involvement of stakeholders. This raises awareness, creates support for the issue and its solutions and increases the likelihood of the recommendations being implemented. Engagement in the evidence-generating process is often at least as important as the actual information produced (Notenbaert et al. 2016b). We thus recommend anchoring the analysis in the real-life context through stakeholder engagement starting from the design and data collection stages. Finally, there is a need to set up appropriate monitoring and evaluation processes and the provision of timely feedback for validation and improvement of the analysis.

Conclusion

Food security, poverty and nutrition are high on the global development agenda. Improving agricultural yields and farmer incomes are often seen as priorities, and development actions are thus designed with these specific aims in mind. The results of the case study presented here show that reduced emission intensity and N losses associated with improved animal genetics, feed and animal health interventions can be synergistic with productivity increases and increased incomes. Combined interventions are estimated to be more environmentally friendly than an isolated one-technology focused approach. The current emphasis on genetic improvement in the mixed systems needs to be carefully revisited and complemented with feed and animal health interventions and advice on appropriate animal husbandry, fertility and manure management.

Due to the current low productivity of the agro-pastoral dairy herds, greater gains in efficiency in combination with relatively low increases in total GHG emissions can be made in these types of enterprises than in the mixed crop-livestock systems. In addition, estimations of large absolute increases in water, land and nitrogen requirements in the mixed crop-livestock systems point to a need for careful management of stocks and quality of these resources. Moreover, an overall rise in GHG emissions is expected, with a maximum of 53% increase associated with an 89% increase in milk supply at the VC level.

The CLEANED tool was developed to support the design of actions to improve incomes and food security in livestock VCs have a minimal environmental footprint. Strengths of the method include the relative ease of use and limited data requirements, in combination with multi-disciplinary impact quantification along different environmental dimensions (in absolute as well as relative terms) and economic feasibility.

The target audience for the framework is decision-makers at different levels such as donors, government agencies and NGOs. It aims to provide them with a rapid ex-ante assessment highlighting potential positive and negative environmental impacts and the trade-offs between them. Specific uses include evaluation of project proposals by donors and providing input in investment decisions of local implementers, both in the private and public sphere.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10113-020-01723-5.

Acknowledgements The work presented in this publication was initiated during the CLEANED LVCs project funded by the Bill and Melinda Gate Foundation (BMGF) and further supported by the BBSRC (BB/L026503/1) and the CGIAR Research Program on Livestock. We thank all donors that globally support our work through their contributions to the CGIAR system.

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